PRELIMINARY FOREST COVER CHANGE ESTIMATES FOR CENTRAL AMERICA (1990'S), WITH REFERENCE TO THE PROPOSED MESOAMERICAN BIOLOGICAL CORRIDOR

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ABSTRACT

The Mesoamerican Biological Corridor (MBC) was established in 1997 by the presidents of the seven Central American nations as a crucial environmental region with a central development concept: integrating conservation, sustainable use, and biodiversity within the framework of sustainable economic development. The following year, in an effort to promote the MBC concept, NASA teamed with the Central American Commission on the Environment and Development (CCAD). A Memorandum of Understanding was signed to initiate research in using remote sensing technology to develop regional forest cover maps and to monitor temporal changes in forest cover throughout Central America and the MBC, as well as facilitate data and technology transfer to Central American participants. This paper describes the data and methods used to develop preliminary estimates of forest cover and forest cover change over the 1990s from seven Landsat Thematic Mapper (TM) study sites across Central America, and in relation to the current and proposed protected areas of the MBC. Results of the analyses suggest that forest clearing rates had declined region-wide for the past decade, as compared to 1980s deforestation estimates from the United Nations Food and Agricultural Organization's (FAO) survey. In addition, forest clearing in areas outside of the current and proposed protected zones was found to be substantially higher than the areas within the MBC.

INTRODUCTION

On December 10, 1998, a Memorandum of Understanding (MOU) was co-signed by Mr. Daniel Goldin, NASA Administrator, and Mr. Miguel Araujo, Central American Commission on the Environment and Development (CCAD). The membership of CCAD includes the governments of Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama. NASA and CCAD recognized the utility of satellite observations for understanding environmental change in Central America. Of particular importance is the Mesoamerican Biological Corridor (MBC), established in 1997 by the presidents of the seven member countries, as a crucial environmental region with a central development concept: integrating conservation, sustainable use, and biodiversity within the framework of sustainable economic development.

The origin of the MBC dates back to the 1980s when Dr. Archie Carr III of the Caribbean Conservation Corporation and the Wildlife Conservation Society (WCS) joined forces to investigate the possibility of establishing a natural corridor through the range of the Florida Panther (Puma concolor coryi). The U.S. Agency for International Development (USAID) provided funds under the project known as Paseo Pantera to strengthen the management of protected areas throughout Central America (Carr 1992). CCAD was established in 1989 and is responsible for coordinating regional environmental activities in Central America. CCAD and the region's governments have endorsed the MBC concept and now, in 2001, there are major donor-funded activities (e.g. World Bank, Global Environment Facility, United Nations Development Program, and USAID, among others) with various goals and commitments to the Corridor concept.

Under the NASA – CCAD MOU, a research grant was awarded in 1998 to the University of Maine, NASA - Global Hydrology Climate Center (GHCC) and NASA - Jet Propulsion Laboratory (JPL) to initiate the research cooperation with the seven Central American countries. The Jet Propulsion Laboratory is leading the regional forest mapping effort using Japanese Earth Resource Satellite (JERS) radar data. The Maine Image Analysis Laboratory is leading the analysis of multidate Landsat - Thematic Mapper (TM) data to estimate forest cover loss (1980's to 1990's), develop land cover maps to support the validation of the JERS regional forest map, and conduct forest fragmentation and other spatial analyses of the proposed Mesoamerican Biological Corridor (MBC). The GHCC at NASA Marshall Space Flight Center is supporting the development of the CCAD web site and Geographic Information Systems as well as the coordination of regional training workshops and central communications between the NASA and CCAD team members.

Recent Remote Sensing and GIS Studies of Forest Change in Central America

With rapid changes in land cover occurring over large areas, remote sensing technology is an essential tool in monitoring tropical forest conditions. The remote and inaccessible nature of many tropical forest regions limits the feasibility of ground-based inventory and monitoring methods for extensive land areas. Initiatives to monitor land cover and land use change are increasingly reliant on information derived from remotely sensed data. An array of techniques is available to detect land cover changes from multi-temporal remote sensing data (Muchoney and Haack, 1994; Jensen, 1996; Coppin and Bauer, 1996). The goal of change detection is to discern those areas on digital images that depict change features of interest (e.g. forest clearing or land cover/land use change) between two or more image dates.

One of the most significant mapping and spatial analysis projects conducted in Central America thus far was the Conservation Assessment of Central American Vegetation and Ecoregions, conducted by The Nature Conservancy, Boston University, and WCS (Li *et al*., 1998) funded through the PROARCA/CAPAS Project. The study used region-wide AVHRR data to develop a detailed vegetation map to support the analysis of conservation protection throughout the ecoregions of Mesoamerica. The AVHRR imagery was recorded in 1992-93, with a pixel resolution of 1km.

Lambert and Carr (1998) conducted a Mesoamerican Corridor suitability analysis using GIS data layers (roads, hydrography, political boundaries, population centers, topography, Holdridge life zones, indigenous areas, and forest/non-forest) derived from a variety of sources and map scales. Their suitability analysis was performed at a four square kilometer resolution to define a "least cost" proposed corridor between Mexico and Columbia. The authors concluded that the study was a preliminary effort with great potential to assist in the prioritization of a proposed corridor, but refinements and higher resolution data (e.g. 1:250,000) were recommended for more detailed regional corridor analysis.

According to the 1990 Food and Agriculture Organization (FAO) Forest Resource Assessment report (FAO, 1993), Central America had one of the highest deforestation rates of any region of the world. The annual rates of deforestation ranged from 1.7% (Guatemala) to 2.9% (Costa Rica) during the 1980's, with the exception of Belize, which had only 0.2% deforestation during this period (FAO, 1993).

Sanchez *et al*. (1999) compared deforestation rates and the extent of fragmentation inside and outside protected areas in the Sarapiqui region of Costa Rica. They reported that the deforestation rate inside protected areas was much lower than outside and the annual rates (inside protected areas) decreased from 0.56% between 1976-86 to 0.16% between 1991 and

1995. Forest fragmentation studies indicated higher fragmentation outside of the protected zones with an increase in the number of patches and a decrease in size from 0.95 to 0.25km^2.

Sader and colleagues (Sader *et al*., In Press) have monitored over ten years of deforestation in the Petén region of northern Guatemala via time series satellite image analysis. As with other regions of Central America, forest is being converted to farmland as slash and burn agriculture advances into the region's Maya Biosphere Reserve (MBR), a series of protected areas and extractive reserves established in 1990 (Sader *et al*., 1997). In comparison to 1980's deforestation estimates (FAO 1993) for Guatemala (1.7%/year), Sader *et al*. (In Press) reported that the annual rate of forest loss within the MBR was lower for 1990-93 (0.23%/year) and 1993-95 (0.33%/year). However, annual forest clearing estimates from 1990-93 to 1993-95 for the MBR's designated buffer zone (2.71% to 3.76%, respectively) were well above the averages reported by the FAO for Central America and Guatemala.

The FAO's Forest Resource Assessment (FRA) 2000 is in progress and the global and regional results are expected in late 2001. The NASA-CCAD project employs TM analysis of forest change, like the FAO-FRA 2000, however the goals, classification schemes and methods are different. The study reported in this manuscript includes a larger sample of the land area (25%) in the Central American region than the FAO study.

Objectives

Given the high rates of deforestation reported for Central America countries in the 1980s (FAO 1993), we conducted a satellite change detection study to determine if the forest clearing rates continued to be high into the 1990s. The specific objectives of this study were to:

1. estimate forest clearing rates (1990s) in Central America based on multi-temporal analysis of seven well-distributed Landsat TM scenes;
2. compare forest clearing rates inside and outside of protected areas of the proposed MBC; and
3. compare the area and percentage of forest cover in the protected areas using the most recent date of Landsat (1996 to 1998).

METHODS

Study Site Selection and Data Acquisition

Eight study areas have been selected throughout the Central America region. The locations of these areas correspond to Landsat TM WRS-2 scene s described in Table 1. The region is composed of many different life zones, topographic variation and land use practices. To develop an effective strategy to monitor the environmental changes in the region, all of the variation in the region must be represented. Each site overlaps two or more countries to foster cooperation between CCAD country researchers in data collection and analysis. The criteria for selecting the study sites included the following:

1. A full range of Holdridge Life Zones are represented.
2. Sites contain biological reserves, protected areas, and a range of land cover/land use.
3. Each of the 7 countries is represented by at least one site and scenes with low cloud cover percentage are available for the late 1980's and mid to late 1990's.
4. Complementary GIS data is available and preferably existing research sites with forest inventory and/or historical aerial photography.

Table 1. Landsat TM study sites in Central America and data acquisition dates.

Landsat Path/Row	NASA Databuy	Pre-Mitch Coverage	USGS Purchase	Other
14 / 54	11 / 17 / 87	None available	12 / 16 / 98	
16 / 50	01 / 28 / 86	Same as USGS	03 / 12 / 96	
16 / 52†	04 / 02 / 86	03 / 12 / 96	12 / 15 / 98	
17 / 49	02 / 01 / 85	02 / 23 / 93	03 / 19 / 96	
18 / 51	02 / 06 / 90	03 / 05 / 94	12 / 29 / 98	
19 / 48	12 / 27 / 89	Clouds unacceptable	05 / 10 / 98	
19 / 50	03 / 20 / 91	05 / 10 / 92	05 / 10 / 98	
20 / 48‡				04 / 14 / 86 04 / 12 / 97

† Scene 16 / 52 not used in the analysis due to severe cloud problems in both the first and last dates of imagery
‡ Scene 20 / 48 data was added to the analysis using forest change data from a previous study (Sader et al., In Press)

The TM data comes from 3 primary sources: 1) the NASA Scientific Data Purchase (Earthsat Corporation), 2) the pre-hurricane Mitch mosaic developed by U.S. Geological Survey (USGS) and 3) selected scenes from the Eros Data Center archives (Table 1). Three TM scenes have been acquired for the following path/row locations of the Landsat Worldwide Reference System (WRS-2): 19/50, 18/51, 17/49, and 16/52. Two TM scenes have been acquired for: 16/50, 19/48, and 14/54. The latter scenes had severe cloud problems, which limited the availability of acceptable data for the project. The data for scene 16/50 had significant cloud cover obscuring land area at both dates, and was not used in the analysis. Scene 20/48 was added to the analysis, using Landsat TM data previously processed in another study (Sader *et al*. In press).

Most of the NASA Scientific Data Purchase scenes were recorded in the mid-to-late 1980's. The subset bands selected for the project were TM bands 3 (visible red), 4 (near infrared) and 5 (first mid-infrared band). Most of the "pre-Mitch" TM data obtained from the USGS Central America mosaic was recorded in the early to mid 1990's. The only bands available were TM 2 (visible green), 4 (near infrared) and 7 (2^{nd} mid-infrared band). Other TM data were acquired from USGS in the late 1990's where we could find scenes with an acceptable low percentage of cloud cover.

GIS layers used in the analysis were acquired from the Environment and Natural Resources Ministry of El Salvador. Specifically, a vector layer containing polygons representing existing and proposed protected areas within the seven Central American nations provided the analysis units for investigating changes in forest cover within the proposed Mesoamerican Biological Corridor. The spatial distribution of the corridor units used in the analysis, along with the locations of the Landsat TM study sites, is shown in Figure 1.

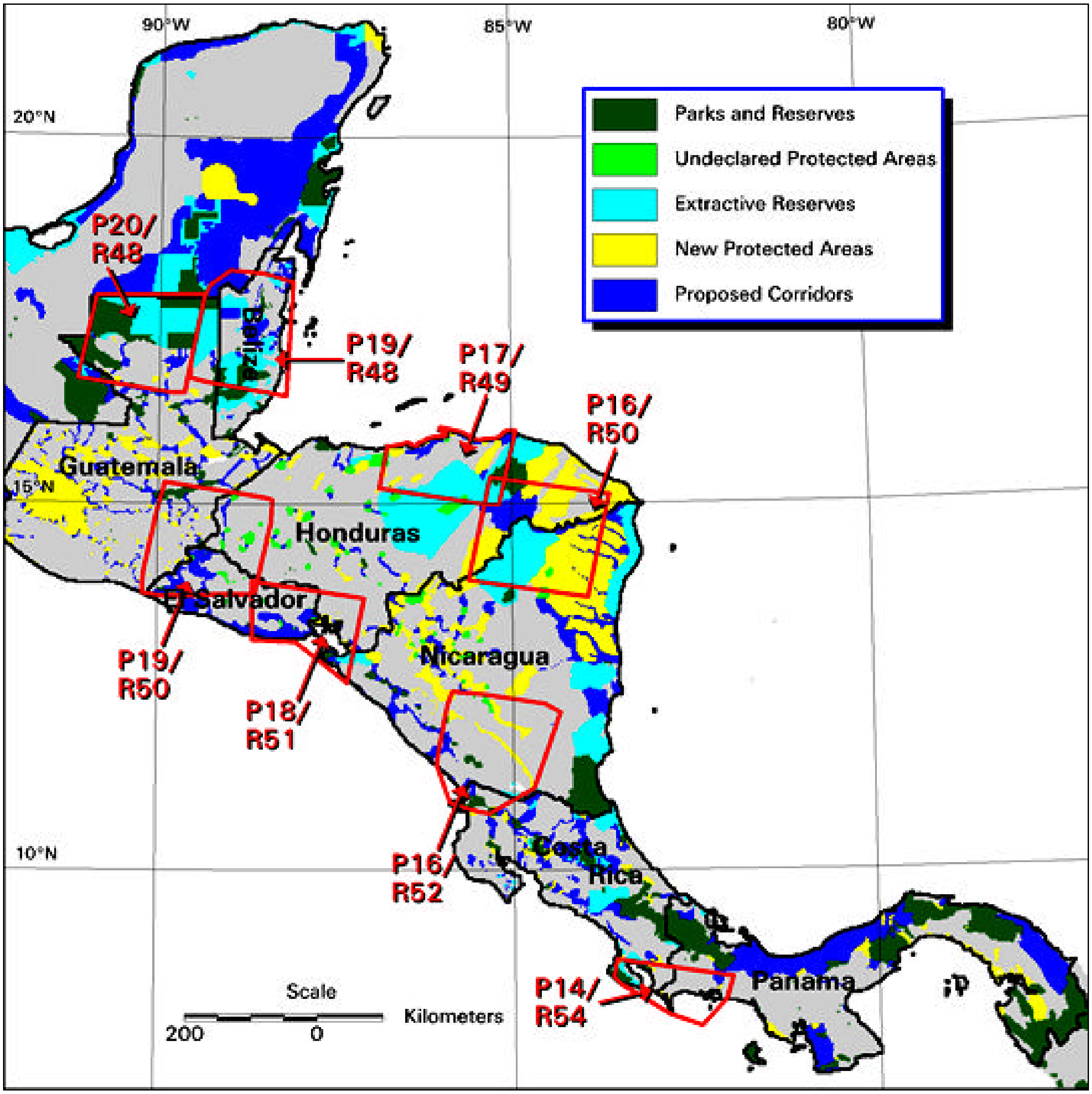

Figure 1. Spatial distribution of the designated protection units of the MBC, in relation to the TM study sites.

Land Cover and Forest Change Classification

All TM scenes were subset to 3 bands to reduce data volume and information redundancy among the 6 reflected TM bands. It has been shown in the research literature that one band in each of the spectral regions (visible, near infrared and middle reflected infrared) are the best combination for vegetation research and land cover mapping applications (DeGloria 1984; Horler and Ahern, 1986).

The orthorectified NASA Scientific Data Purchase images were used as the base maps to geo-reference the Mitch and

USGS scenes. Scene to map rectification was performed by selecting well-distributed ground control points (GCP's) and transforming each data set to the UTM map projection and pixel size (30m). The root mean square error for all scenes was less than 1 pixel. A nearest neighbor resampling method was employed.

Radiometric corrections were not performed on the TM data as the goal of the study was to distinguish only forest cover against non-forest areas rather than more detailed land cover types. We reasoned that, for the time and effort involved, the noise levels in the data that might be compensated by a radiometric correction procedure would be well below the coarse level of forest / non-forest reflection differences that we could classify. Other studies have indicated that radiometric corrections did not produce significantly higher forest change classifications in situations where only binary classification schemes (e.g. forest vs. non-forest) were involved (Lyon *et al*., 1998; Sader *et al*., In press; Tokola *et al*., 1999).

Changes in forest cover between the first and last dates of each TM scene were extracted using a post-classification change detection approach. For each date, separate unsupervised classifications were performed to identify areas of forest from non-forest. Fifty clusters were developed for each image using the ERDAS Imagine (v8.4) "isodata" routine (ERDAS, Inc. 1999). Clusters representing clouds, cloud shadows, and water were identified and removed from the analysis. The remaining clusters were recoded to create forest / non-forest maps for each date. Note that natural non-forest areas (e.g. wetlands, savanna, etc.) were not separated from anthropogenic non-forest areas (agriculture, urban), thus only changes in forest cover were analyzed. The forest / non-forest images from the two dates of each scene were then combined to highlight areas of unchanged forest, non-forest, and forest clearing (forest at the first date to non-forest at the second). Each of the combined images were subjected to detailed visual analysis, using the original TM data from each date to identify and correct areas of false-change and misclassification.

Following classification and editing of the TM imagery, forest change data were analyzed within the corridor units that coincided with the study sites. The polygon coverage containing the protected and proposed units of the Mesoamerican Biological Corridor was converted to a raster image for analysis with the forest change classification for each study site. Statistics on forest cover and forest change for each corridor unit were extracted from the change images using the "summary" routine (ERDAS, Inc. 1999). To allow a comparison of forest clearing among TM scenes, we used the following formula:

$$\left(\frac{F_1 - F_2}{F_1} * 100\right) \Big/ \# years \qquad \text{(Eq. 1)}$$

where F_1 is the area of forest cover at the first date, F_2 is the area of forest cover at the second date, and #years is the period (in years) between the first and second TM scene acquisition dates.

RESULTS

Forest Cover and Forest Change Rates

We report forest cover and forest clearing rates based on the seven TM study sites in our analysis. The amount of land area represented in each study site is variable depending on the proportions of land and water and the amount of cloud cover that had to be edited out of each TM scene. The total land area in the seven study sites was approximately 133,675 km^2. This represents 25.7% of the total land area in the seven Central American nations and 31.1% of the land area within the protected zones of the proposed MBC (Table 2).

Table 2. Land area within MBC zones represented by the area classified in the TM study sites.

Protection Zone Status	Total Area of 7 Countries (km^2)	% of 7 Country Total	Area within TM Sites (km^2)	% of 7 Countries Represented by TM Sites
Parks and Reserves	47,689	9.16%	11,219	23.53%
Undeclared Protected Areas	6,279	1.21%	1,493	23.78%
Extractive Reserves	52,789	10.13%	26,371	49.95%
New Protected Areas	64,594	12.40%	16,662	25.80%
Proposed Corridor	57,855	11.11%	15,575	26.92%
MBC Total	**229,206**	**44.00%**	**17,321**	**31.12%**
Outside the MBC	291,701	56.00%	62,353	21.38%
7 Countries Total	**520,907**	**100.00%**	**133,674**	**25.66%**

Among the TM study sites, the forest cover, in percent of the total land area classified, ranged from 13.6% (site 19 / 50) to 82.6% (site 16 / 50). The average forest cover over all seven study areas was 57.3% in the mid-to-late 1990s (1996-98). The time periods for the change detection analysis varied from 7 to 11 years, with the median period being 10 years (Table 3). Annual forest clearing rates ranged from 0.16% (site 16 / 50) to 1.28% (site 19 / 50). The mean clearing rate for the seven TM study sites combined was 0.58% per year.

The percentage of forest cover over the total classified land area inside the proposed and current protection zones of the MBC was substantially higher (80.4%) compared to forest cover over the entire study area (57.3%). The lowest forest cover percentage was 26.3% (site 19 / 50), while the highest was 92.9% (site 20 / 48). The latter site covers the Maya Biosphere Reserve and its buffer zone in the remote Petén district of northern Guatemala, where relatively few roads penetrate the reserve areas. In every site, the percentage of forest cover was higher inside the protection zones compared to the entire classified TM scene area (Table 3).

Table 3. Annual forest clearing rates within the protected and proposed MBC zones, by TM site.

Landsat Path/Row	Countries	% Forest	Year	%/Year Total Forest Cleared	% of MBC area in Forest	%/Year Forest Cleared in MBC	# Years
14 / 54	Panama, Costa Rica	35.3%	1998	0.26%	65.7%	0.17%	11
16 / 50	Nicaragua, Honduras	82.6%	1996	0.16%	87.8%	0.15%	10
17 / 49	Honduras	63.6%	1998	0.49%	75.8%	0.33%	11
18 / 51	Honduras, El Salvador, Nicaragua	14.5%	1998	0.47%	31.0%	0.34%	8
19 / 48	Belize, Guatemala	78.5%	1998	0.61%	89.6%	0.31%	9
19 / 50	Guatemala, El Salvador, Honduras	13.6%	1998	1.28%	26.3%	0.60%	7
20 / 48	Guatemala	76.7%	1997	0.97%	92.9%	0.32%	11
Total		**57.3%**		**0.58%**	**80.4%**	**0.26%**	**10**

We took a closer look at the forest status in each designated protected zone of the MBC using the second date of imagery for all seven TM study sites. The total area of forest cover, the percentage of forest cover, and annual forest clearing rates in each MBC zone are reported in Table 4. The forest cover percentage ranged from 57.3% in undeclared protected areas to 93.8% in current parks and reserves (mean = 80.4%). For comparison, only 30.8% of the total land area classified outside the MBC protected zones was represented by forest cover. Among the five MBC protection zones, annual forest clearing rates were lowest in designated extractive reserves (0.15%) and were highest in areas proposed for addition to the protected corridor (0.57%). New protected zones, parks and reserves, and protected zones without declaration all had similar clearing rates of 0.22%, 0.25%, and 0.26% per year, respectively. Forest clearing outside of the current and proposed protected zones was substantially higher (1.44% per year) than the areas within the MBC (0.26% per year).

Table 4. Annual forest clearing rates for protection zones of the proposed MBC; all TM sites combined, based on a 10 year median.

Protection Zone Status	Area of Forest Remaining (km^2)	%Forest Remaining	%/Year Forest Clearing
Parks and Reserves	812	93.77%	0.25%
Undeclared Protected Areas	854	57.23%	0.26%
Extractive Reserves	24,123	91.48%	0.15%
New Protected Areas	12,692	76.17%	0.22%
Proposed Corridor	9,169	58.87%	0.57%
MBC Total	**57,358**	**80.42%**	**0.26%**
Outside the MBC	19,196	30.79%	1.44%
7 Countries Total	**76,554**	**57.27%**	**0.58%**

DISCUSSION

The results of the forest cover and forest clearing analysis reported here are very preliminary. Accuracy assessment of the forest cover and change classifications are not yet completed, but planned for the spring of 2001. It should be noted that at this stage much work has been done in the form of post-classification editing to reduce misclassification between forest cover and high-reflectance agricultural crops (e.g. sugar cane) as well as confusion between non-target change in crop cover types as opposed to forest to non-forest conversion. This procedure serves to minimize commission error in the forest clearing category by removing areas of false-change using on-screen digitizing. However, this procedure does not address errors of omission in the forest clearing category, the result being conservative estimates of forest change over the study sites. More classification refinements and editing will likely be required in the final stages of analysis.

We use the term "forest cover" in a broad sense in this manuscript; we do not have a strict definition at this time. In fact, we are certain that some of the area we identified as forest is actually composed of agroforestry and plantation forestry uses. For example, coffee, a major cash crop in most Central American countries, is often planted under the shade of trees and so is undistinguishable from natural forest on TM imagery.

These preliminary findings indicate that the extent of forest cover under protection status, in some of the study sites, is quite low (e.g. sites 19 / 50 and 18 / 51), which has some implications for the conservation of biodiversity along the MBC. Forest clearing rates for the 1990s in Central America appear to have dropped to lower levels compared to that of the 1980s, as reported by the FAO – Forest Resources Assessment (FAO 1993). The FAO estimates ranged from 1.7% to 2.9% per year for the Central American countries (excluding Belize), while our preliminary results for the 1990's indicate an annual clearing rate of 0.58% (Table 4).

CONCLUSIONS

Although protection status affords some conservation of forest cover in the MBC (80% forest cover inside the protected zones compared to 31% outside), there are some designated zones that have very low proportions of forest cover. One finding of particular interest in this study was the percentage of forest remaining and the forest clearing rates in the proposed corridor areas. This zone had only 59% forest cover of the classified land area, along with an annual clearing rate that was twice as high (0.57%) as the next highest protected zone designation. If these proposed corridors are to be linked to the currently protected zones of the MBC then the forest cover losses and fragmentation occurring in these zones should warrant serious consideration by Central American governments and the conservation community. There are many issues related to proposed corridor designation that are under discussion. Indigenous organizations objected to being left out of the initial planning process. It is quite possible that some new boundaries will be redefined for "proposed corridors" once all of the stakeholders deliberate on this important issue for Central America.

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